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(58) Field of search G5R

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(54) Apparatus for recording data in a disc-shaped optically readable record carrier

(57) A periodic track modulation is or has been formed in the record carrier, whose period corresponds to a frequency for which the random power spectrum of the digitally coded information to be recorded or recorded at least substantially exhibits a zero point, in order to generate a clock signal of bit frequency during recording or reproduction.

Said periodic track modulation has a phase which shifts from track to track in the radial direction B in order to indicate an undesired transition from one track to an adjacent track during recording and to interrupt the recording process in due time in order not to write over the adjacent track.

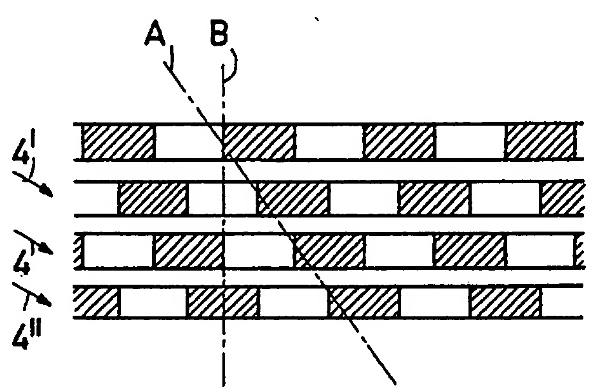

FIG.14

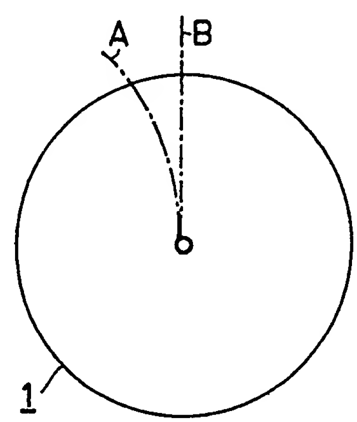

FIG.15

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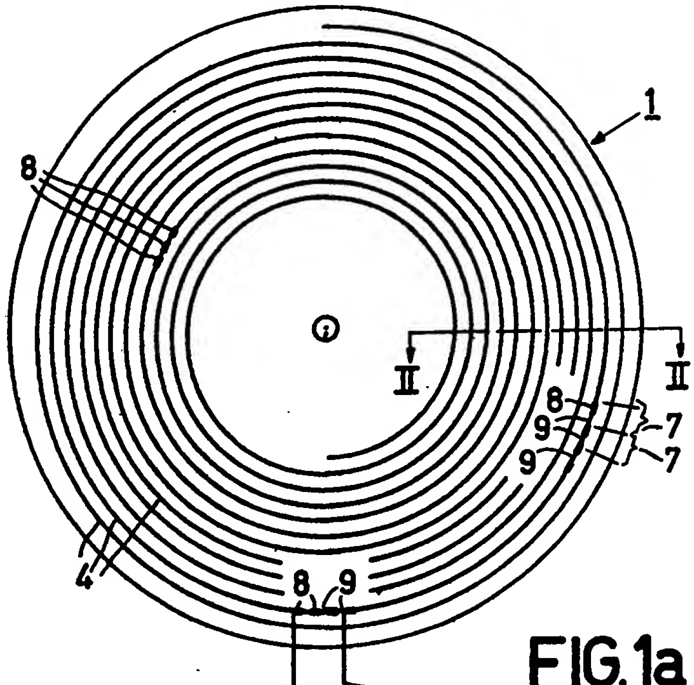

FIG.1a

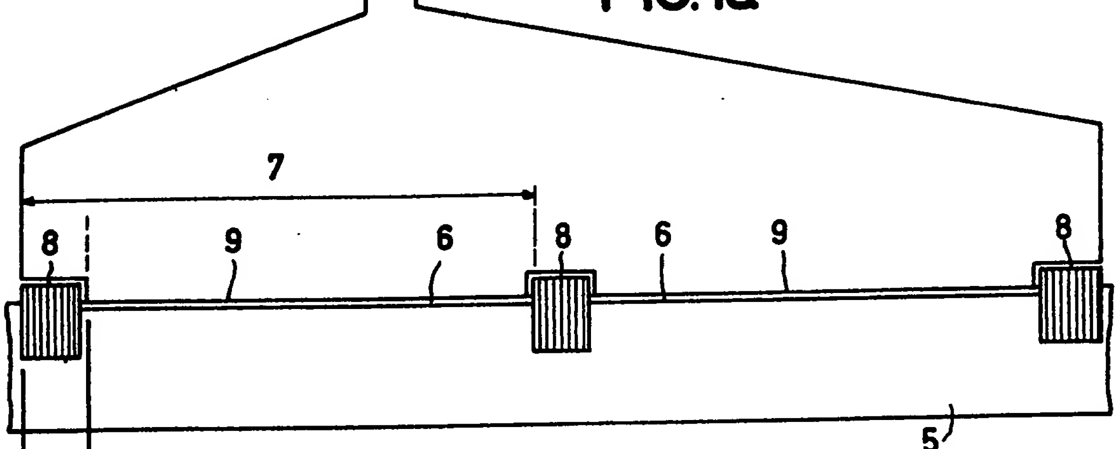

FIG.1b

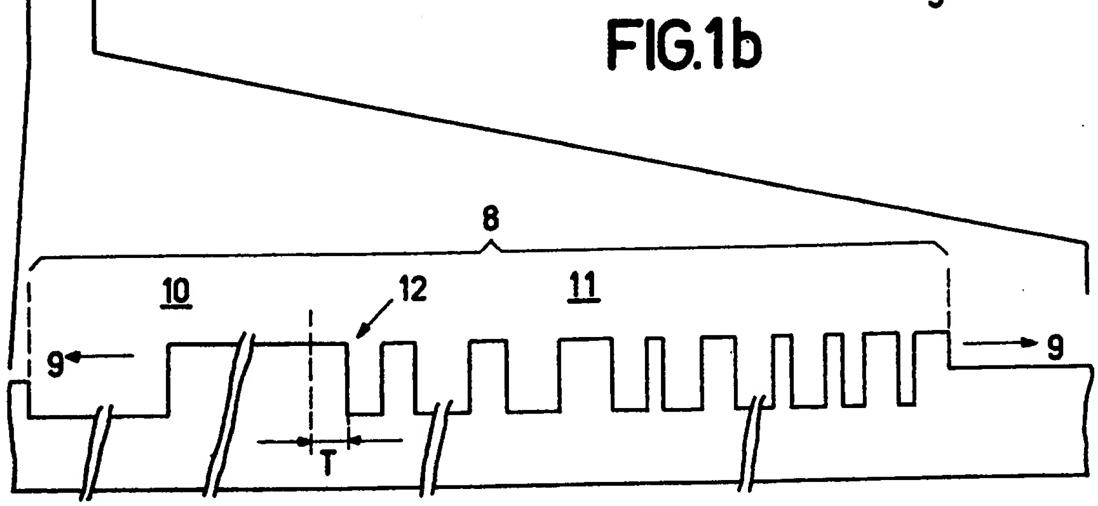

FIG.1c

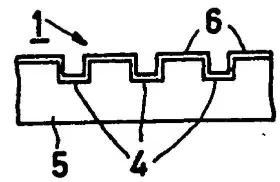

FIG.2

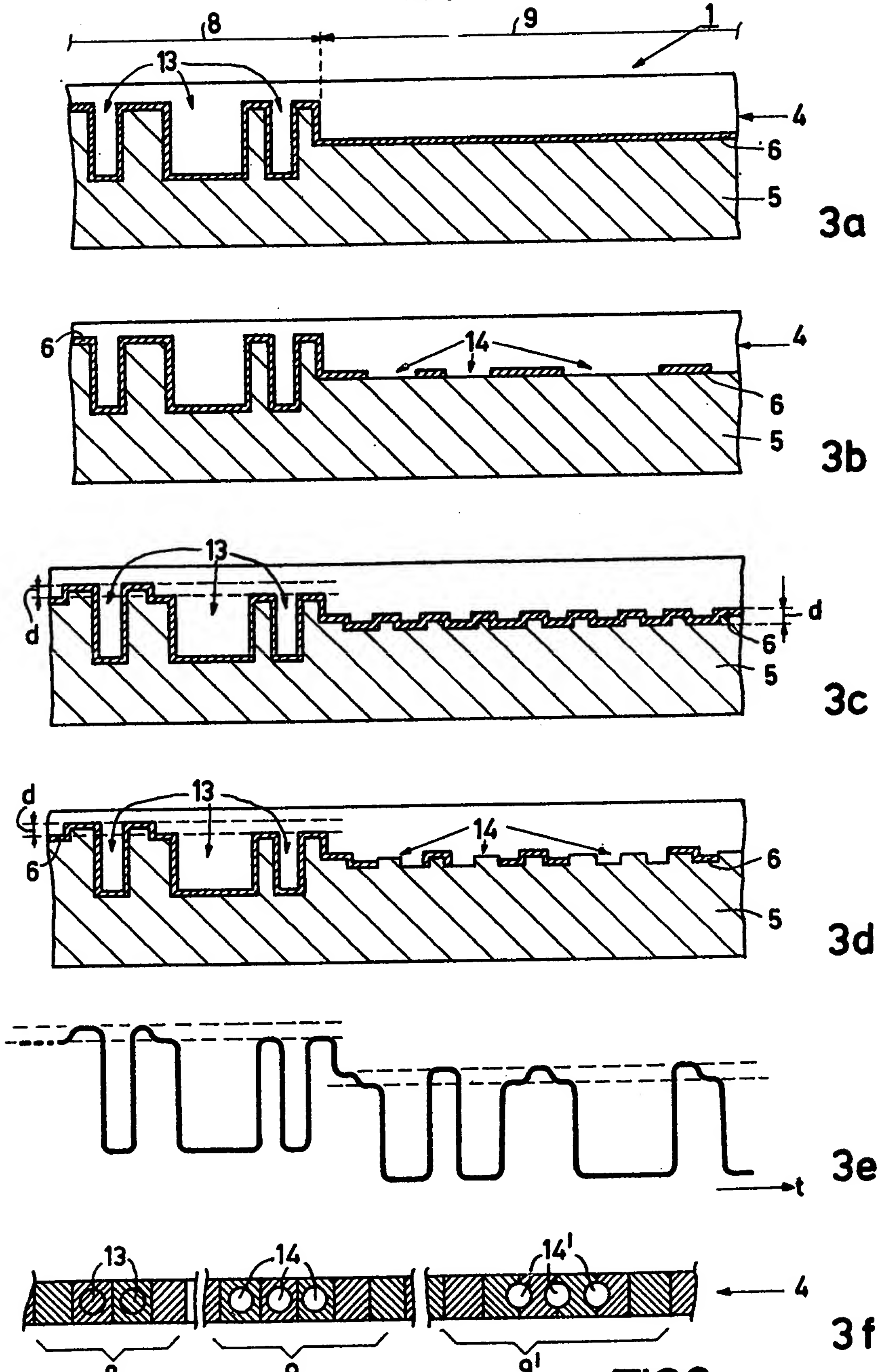

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FIG.3

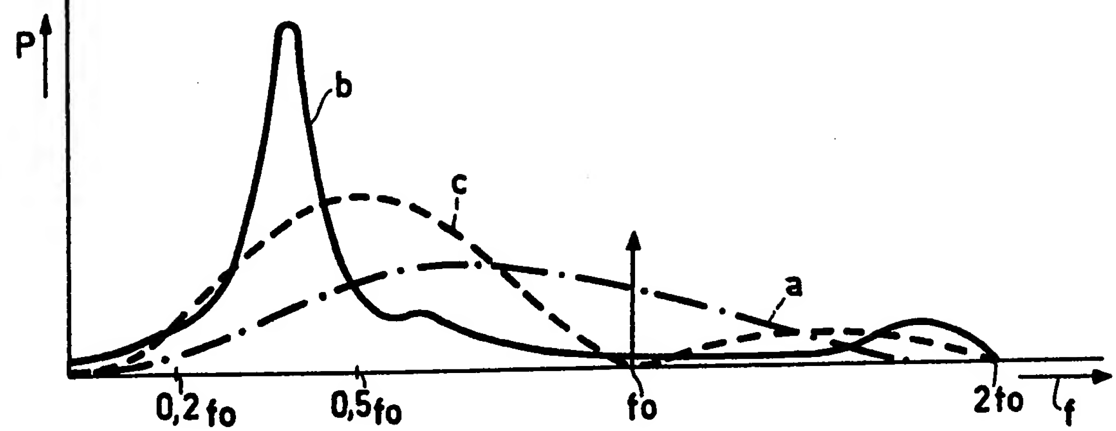

FIG.4

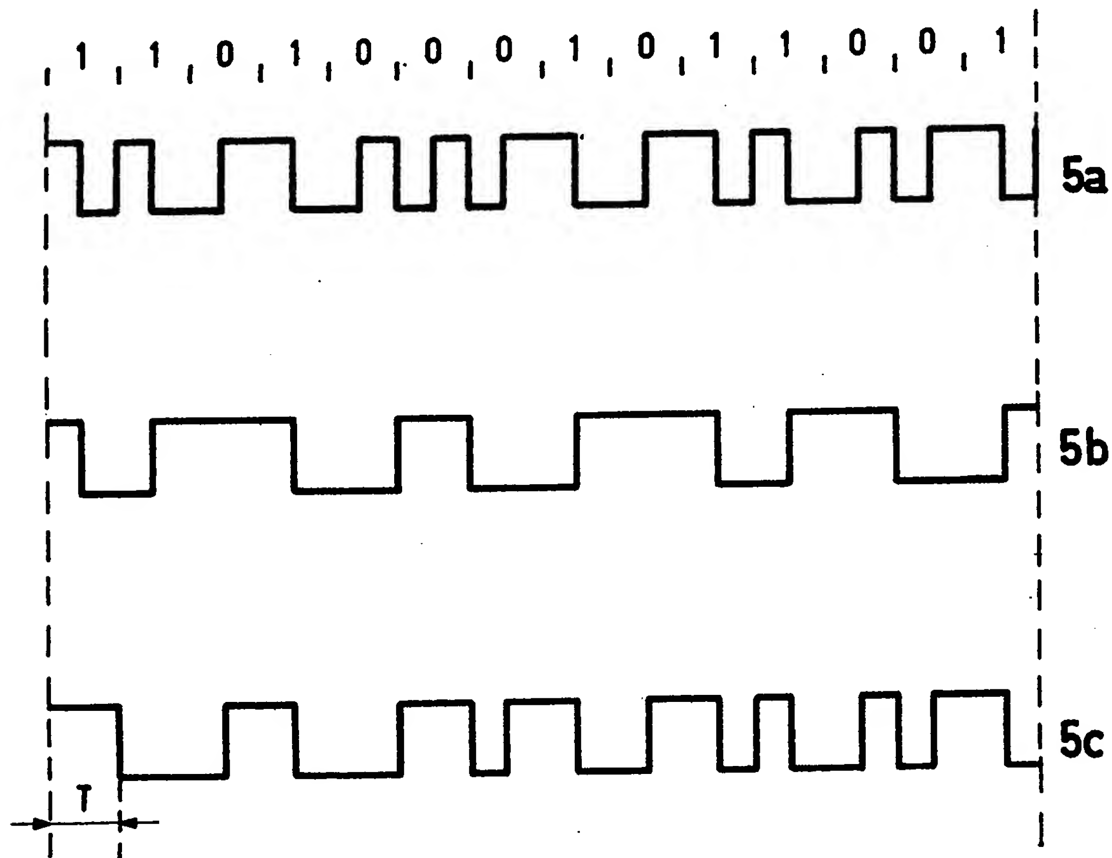

FIG.5

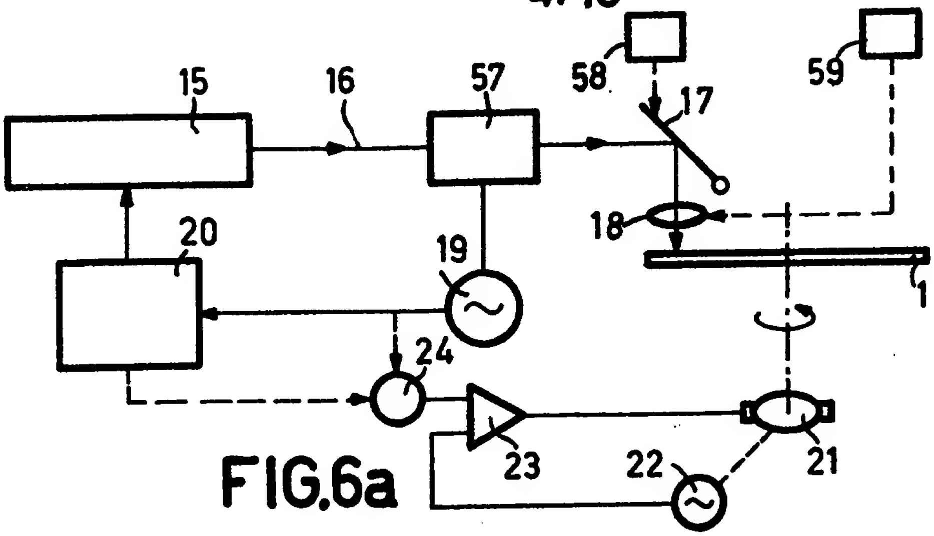

FIG.6a

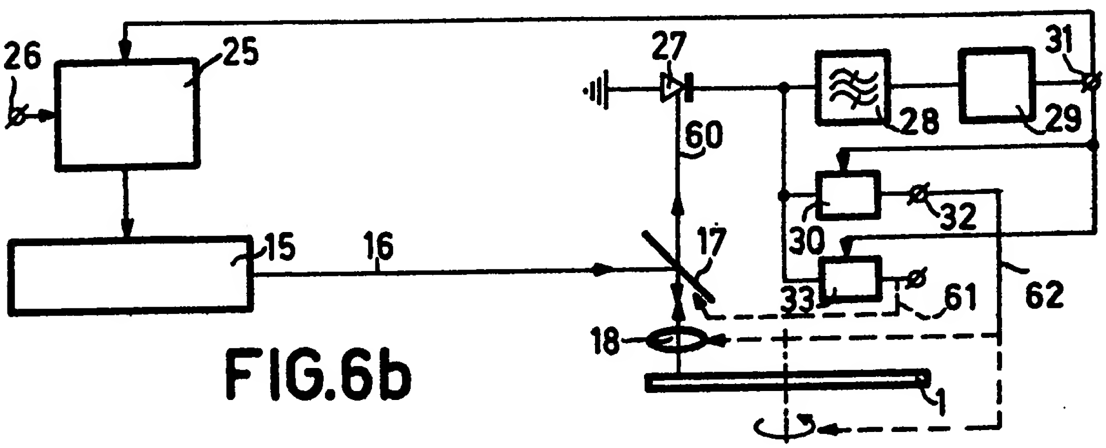

FIG.6b

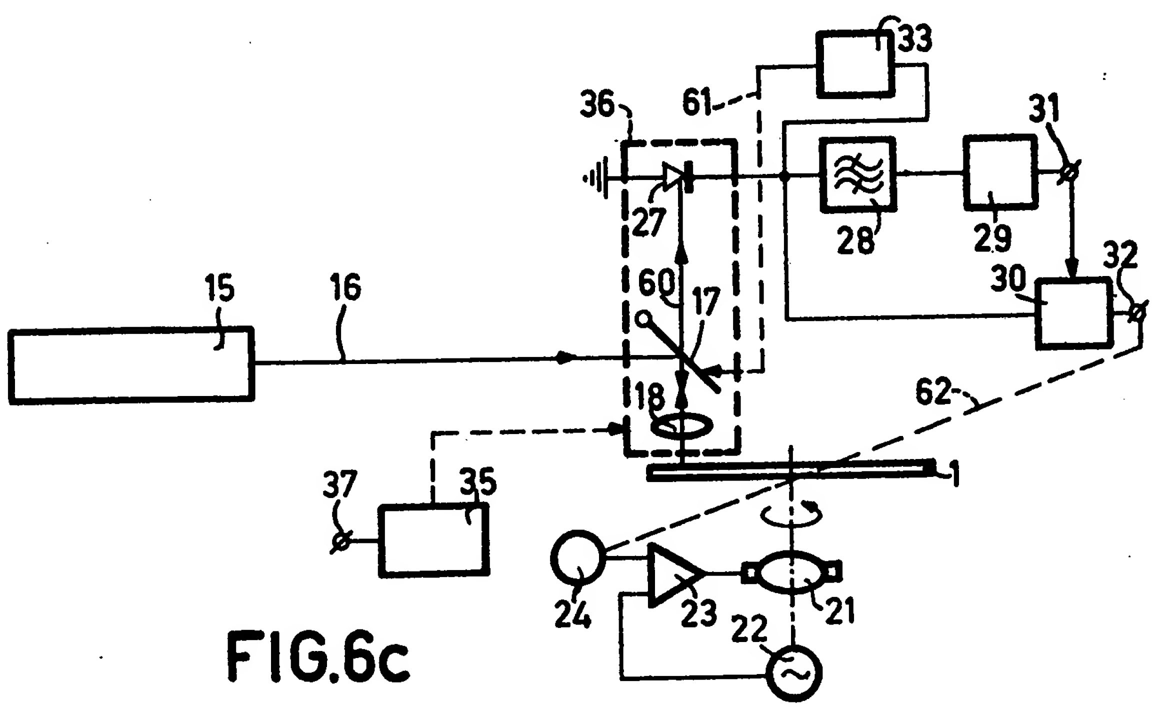

FIG.6c

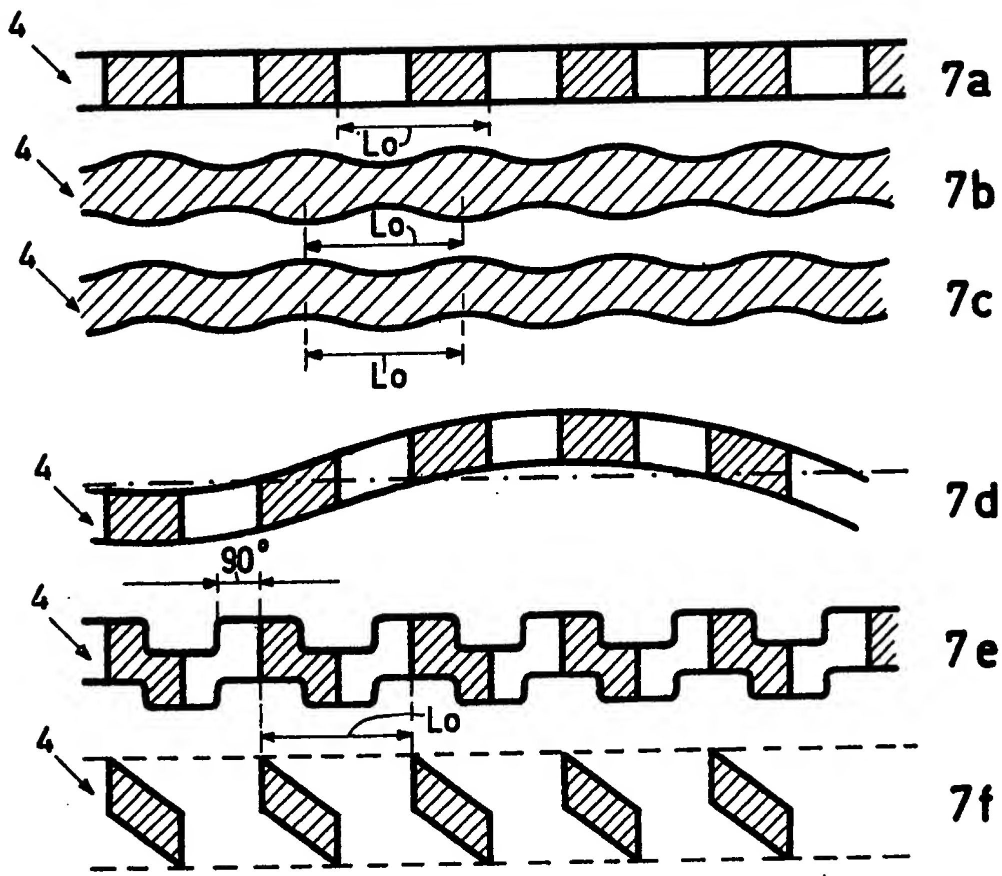

FIG. 7

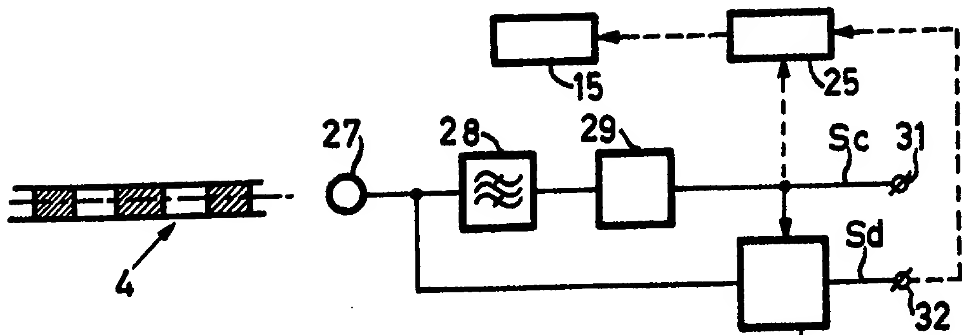

FIG.8a

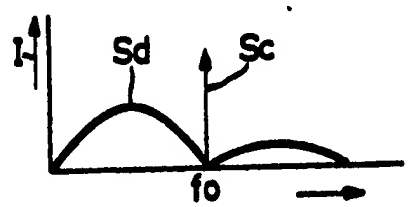

FIG.8b

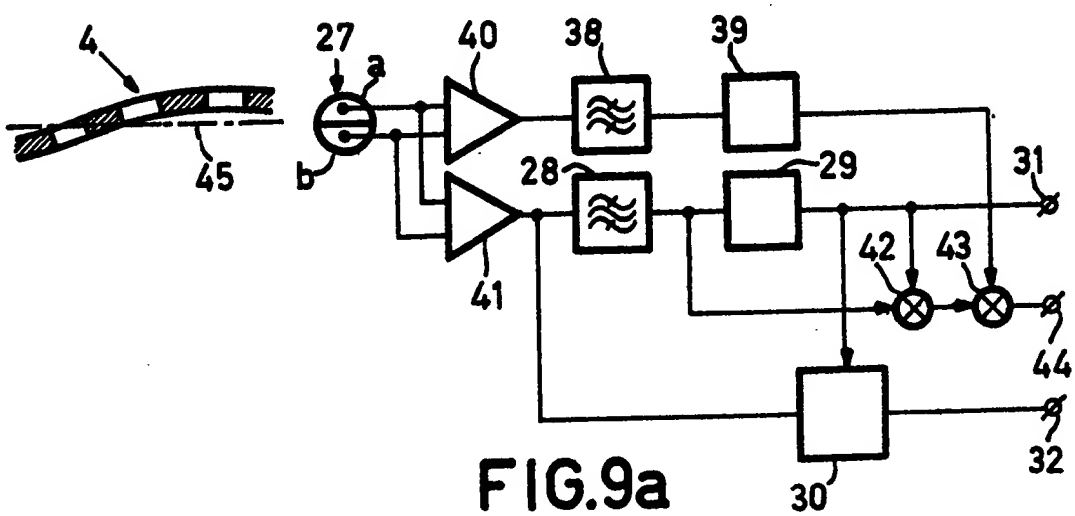

FIG.9a

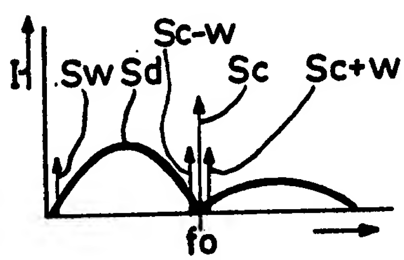

FIG.9b

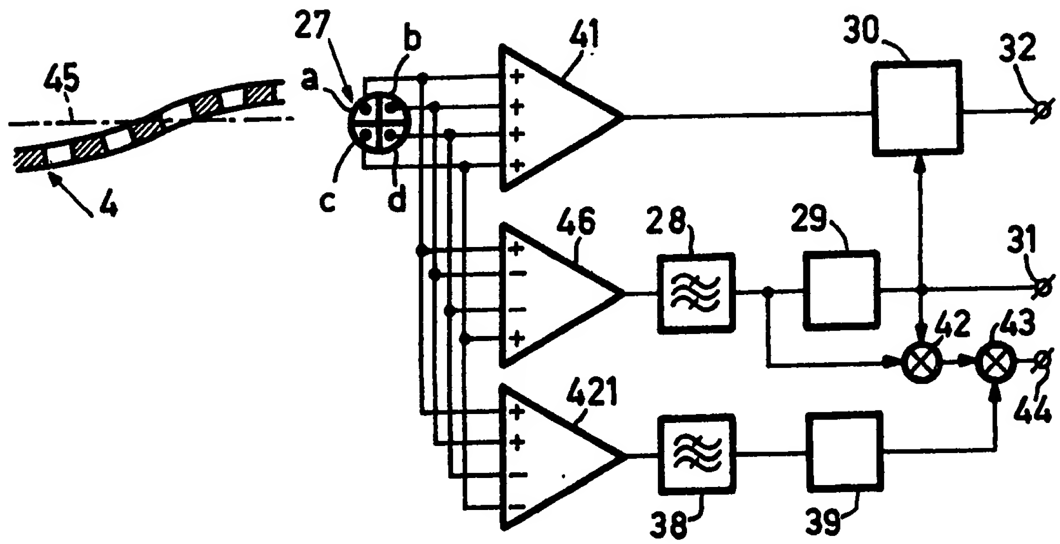

FIG.10

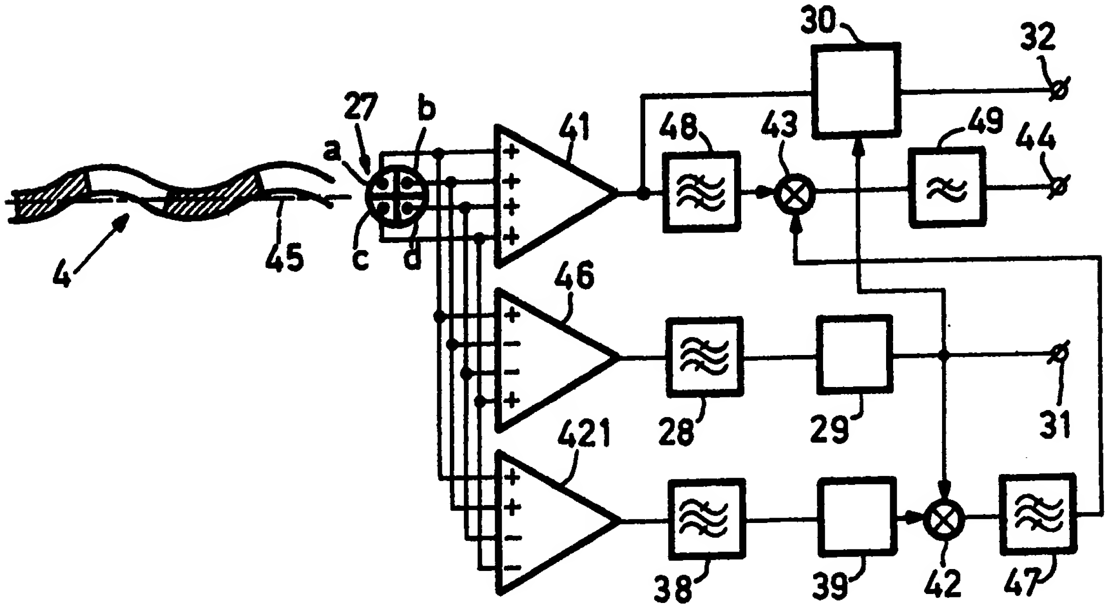

FIG.11a

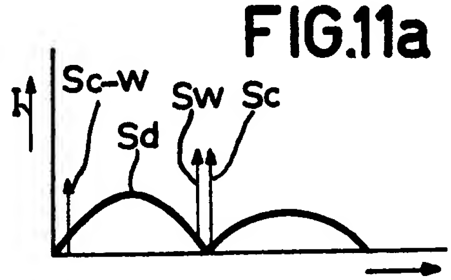

FIG.11b

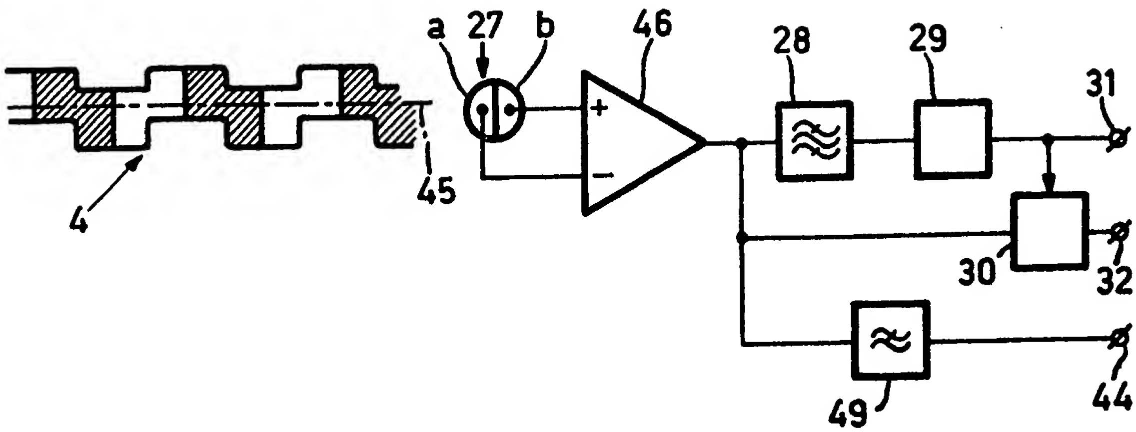
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FIG.12

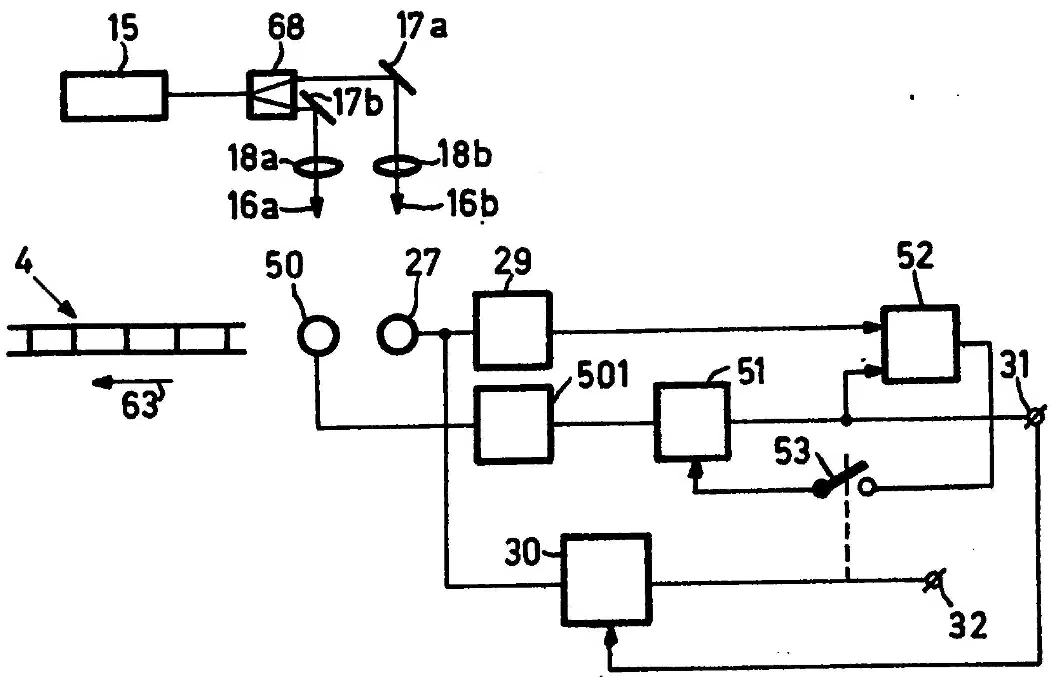
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FIG.13

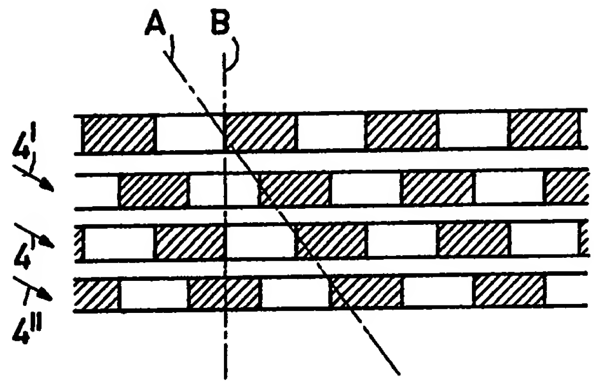

FIG.14

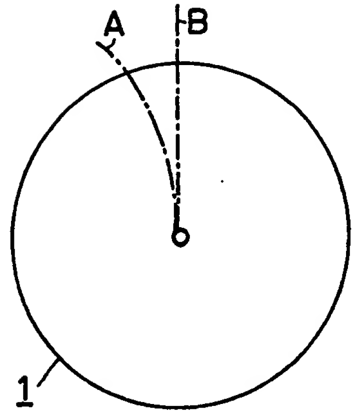

FIG.15

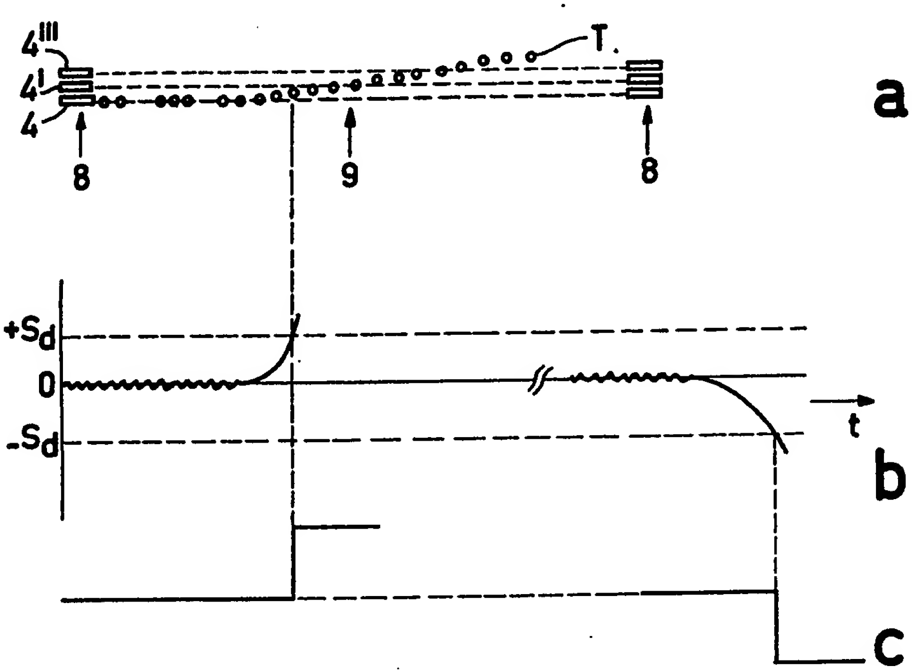

FIG.17

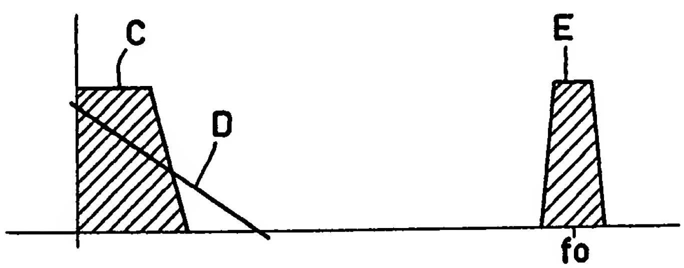

FIG.18

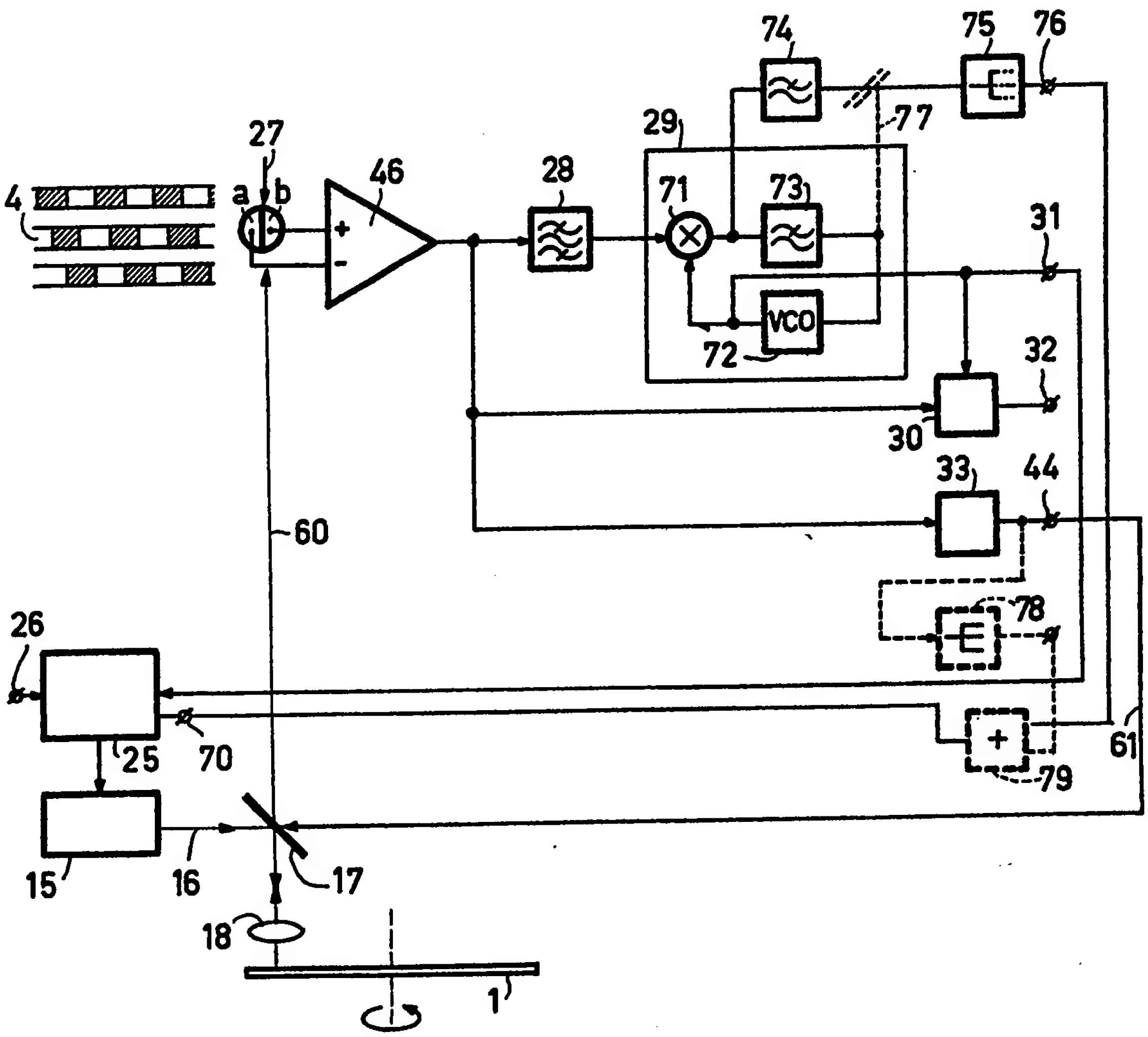
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FIG.16

SPECIFICATION

Apparatus for recording data in a disc-shaped optically readable record carrier

The invention relates to an apparatus for recording information on a record carrier comprising a disc-shaped substrate with a radiation-sensitive information layer and provided with information areas arranged in accordance with a spiral or concentric track pattern, the apparatus including a light source, an optical system for directing a light beam to the information areas of said record carrier, a recording circuit for modulating the light beam depending on the digital signal to be recorded, and an optical system with a detector for detecting the radiation which is reflected or transmitted by the record carrier.

A record carrier of the type mentioned in the opening paragraph and apparatus for recording and/or reading information on and/or from such a record carrier is known from Netherlands Patent Application No. 7802859, which has been laid open to public inspection, in which record carrier the information areas alternate with synchronization areas, which each contain the address of the information area that follows such a synchronization area. When such a record carrier is used the clock generation is intricate and sometimes not very reliable. During reading it is possible though intricate to derive a clock signal from the recorded data signal and the information signals recorded in the synchronization areas. When recording the data signal in the information areas the clock generation is even more intricate, because then only the information contained in the synchronization areas is available in which case a clock generator may be used, which generator during reading of the synchronization areas can be synchronized with the information contained in said synchronization areas by means of a phase-locked loop, which apart from said complexity has the additional drawback that at the beginning of each synchronization area said phase-locked loop should be locked in again and that the synchronism of the record carrier motion with the process of the recording data in the information areas is not reliable, so that not every information area is utilized up to the end because space is to be reserved in order to allow for the effect of possible speed variations of the record carrier and of the information recording process as a result of drift of the frequency of the clock generator. Said Patent Application therefore proposes to include additional synchronization areas in the information areas, which mitigates said problems but does not eliminate them and which reduces the information storage capacity of the record carrier. In record carriers which do not employ synchronization areas between the information areas, such as for example record carriers for recording digitally coded audio signals, the clock generation is even more intricate.

The solution proposed in the Applicant's pending British Patent Application 8100124, published under Serial No. 2069219A is to provide the tracks of the record carrier in advance with a periodic track modulation in order to simplify clock generation. The present Application includes said previous Application as Figures 1 to 13 of the accompanying drawings together with the associated description.

An apparatus of the type mentioned in the opening paragraph presents another problem. When digital information is recorded the reliability of the recorded information should be very high. To this end a number of methods are proposed in order to correct errors in the recorded data signal. An annoying error, which cancels the effect of all steps taken to increase the reliability, occurs if during recording the laser beam unintentionally comes off the track and "scratches" over the information already recorded. If this happens said "scratch" will extend through the information in adjacent sectors owing to the inertia of a radial tracking system which is used (for this see *inter alia* USP 4,223,187), so that much information within one information area will be damaged. This is a situation which cannot even be rectified by very effective error correction methods.

A possible solution is to monitor the signal of the radial tracking system and if said digital exceeds preset limits to interrupt the recording process and to re-record the information in another information area. Erroneous interruption of the recording operation may then give rise to unnecessarily re-recorded information areas and failure to interrupt the recording operation may degrade reliability of the recorded information. The method proposed here, to monitor the radial tracking signal, is not entirely satisfactory in this respect, because this method derives its information from a part of the signal spectrum of comparatively low frequency and is therefore rather sensitive to non-disastrous faults, such as variations in the reflection coefficient of the disc and local flaws in the disc, which are faults which do not give rise to a tracking error but which may cause the beam to move to another track, so that interruption of the recording process should not be necessary but nevertheless occurs.

It is an object of the invention to provide an apparatus of the type mentioned in the opening paragraph, which does not present said problems.

According to the invention there is provided an apparatus for recording information on a record carrier comprising a disc-shaped substrate with a radiation-sensitive information layer and provided with information areas arranged in accordance with a spiral or concentric track pattern, the apparatus comprising a light source, an optical system for directing a light beam to the information areas of said record carrier, a recording circuit for modulating the light beam depending on the digital signal to be recorded, and an optical system with a detector for detecting the radiation which is reflected or transmitted by the record carrier, wherein for reading a record carrier in which the information areas exhibit a periodic track modulation, whose period corresponds to a

frequency for which the power spectrum of the digitally coded information to be recorded or recorded at least substantially exhibits a zero point, for generating a clock signal of bit frequency for synchronizing the digitally coded information during recording and/or reproduction, said periodic track modulation being formed in the track in such a way that from track to track points of said track modulation of equal phase extend along a line which departs from the radial direction, so that the track modulation of each track as a function of the circumferential angle of the disc-shaped record carrier in the one radial direction always has a phase lead relative to track modulation of the adjacent track in said radial direction and in the other radial direction has a phase lag relative to the track modulation of the adjacent track in said other radial direction, the apparatus further comprises a band-pass filter for filtering a signal of a frequency determined by the period of the periodic track modulation out of said detected radiation, which signal is applied to a write circuit as a clock signal for synchronizing the information signal to be recorded with the periodic track modulation in such a way that the information to be recorded is recorded in a fixed phase relationship with said periodic track modulation and a phase comparison circuit for monitoring the instantaneous phase of said filtered signal in order to generate a signal for interrupting the recording process when the phase deviates to a predetermined extent from that of a signal of monotonously varying phase.

The invention is based on the recognition, that in the system proposed in said previous Application, where a frequency which is in synchronism with the bit frequency of the data signal to be recorded is prerecorded on the record carrier, which frequency can be detected both during information reading and writing without any significant interference with said data signal and without loss of storage capacity, so that always a highly synchronous and reliable clock signal is available, it is possible by monitoring the phase variation of the periodic track modulation to obtain a signal which indicates whether the write beam deviates from the desired track to an impermissible extent, because then the shifted phase of the adjacent track is detected. This method is less suceptible to low-frequency interference because the information is derived from a high-frequency signal.

In an embodiment of this apparatus the phase comparison circuit is included in a phase-locked loop, said phase comparison circuit receiving said filtered signal and the signal from an oscillator which is controlled by the output signal of said phase comparison circuit *via* a low-pass filter, the output signal of said phase comparison circuit being applied to a window detector.

Said apparatus, provided with optical means for directing a light beam modulated with information to be recorded to the information areas and for directing an auxiliary beam to the information areas behind the modulated beam in order to read the information recorded by the modulated light beam, may further be characterized in that the auxiliary beam for reading the periodic track modulation is used for generating the clock signal in order to synchronize the information recording process with the other beam and for supplying the signal to the phase comparison circuit.

The present invention will now be explained and described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows a possible embodiment of a record carrier to which the invention principle may be applied, Figure 1*a* being a plan view of the record carrier, Figure 1*b* showing a part of a track 4 of said record carrier on an enlarged scale, and Figure 1*c* showing a synchronization area of said part on an enlarged scale,

Figure 2 shows a small part of the cross-section taken on the line II—II of Figure 1*a*,

Figure 3, in Figures 3*a* to 3*d*, schematically shows a cross-section in the longitudinal direction through a part of the track 4, Figure 3*a* showing such a cross-section for a blank prepared disc in accordance with a known technology, Figure 3*b* showing said cross-section of Figure 3*a* after information has been recorded in the information area 9, Figure 3*c* showing such a cross-section of a blank prepared disc in accordance with the method disclosed in British Patent Application 8100124, Figure 3*d* showing the cross-section of Figure 3*c* after digital information has been recorded; Figure 3*e* schematically represents the signal obtained when reading the part of the track 4 shown in cross-section in Figure 3*d*, and Figure 3*f* schematically represents a plan view of a part of the track 4 after digital information has been recorded in a manner other than in Figures 3*b* and 3*d*,

Figure 4 shows the random power spectra of three digital information signal modulations,

Figure 5 is a diagrammatic representation of said modulations,

Figure 6 in Figure 6*a* schematically represents an apparatus for manufacturing a record carrier in accordance with Figure 3*c*, Figure 6*b* schematically represents an apparatus for recording information in the record carrier of Figure 3*c*, and Figure 6*c* represents an apparatus for reading an inscribed record carrier,

Figure 7 shows a number of examples of a periodic track modulation,

Figure 8*a* illustrates schematically a read section of an apparatus for reading and/or recording a digital signal on a record carrier and Figure 8*b* represents the frequency spectrum of the signal detected by the detector 27,

Figure 9*a* shows an apparatus in accordance with Figure 8*a*, which is also suitable for generating a radial tracking signal, Figure 9*b* represents the frequency spectrum of the signal detected by the detector 27,

Figure 10 shows a variant of the apparatus of Figure 9*a*,

Figure 11*a* shows an apparatus in accordance with Figure 9*a* adapted to a record carrier with a

radial track modulation of substantially the same period as the periodic track modulation and Figure 11*b* represents the frequency spectrum of the signal detected by the detector 27,

Figure 12 shows an apparatus adapted to a record carrier with a radial track modulation of the same period as the periodic track modulation,

Figure 13 show a part of an apparatus for recording an information signal on a record carrier and for generating a clock signal, use being made of an auxiliary laser beam,

Figure 14 shows a modification of the periodic track modulation shown in Figure 7,

Figure 15 shows a record carrier provided with a periodic track modulation in accordance with Figure 14,

Figure 16 shows an apparatus for inscribing a record carrier provided with a periodic track modulation, and

Figures 17 and 18 shows some diagrams illustrating the operation of the apparatus shown in Fig. 16.

Figure 1 shows a possible embodiment of a record carrier to which the invention principle may be applied, Figure 1*a* showing a plan view of this record carrier, Figure 1*b* showing a part of a track 4 of said record carrier on an enlarged scale, and Figure 1*c* showing a synchronization area of said part on an enlarged scale. The record carrier body 1 is provided with a spiral track 4. This track 4 is divided into a multitude of sectors 7, for example 128 per revolution. Each sector 7 comprises an information area 9, intended for recording digitally coded information, and a synchronization area 8.

In order to ensure that the digital information is recorded in an accurately defined path the track 4 is employed as a servo track. For this purpose the information areas 9 of the sectors 7 exhibit an amplitude structure, as is shown in Figure 2. This Figure 2 shows a small part of the cross-section taken on the line II—II in Figure 1*a* and thus shows a number of adjacent track portions, specifically information areas, of the servo track 4. The direction of the servo tracks 4 is thus perpendicular to the plane of drawing. Said servo tracks 4, in particular the information areas 9, thus take the form of grooves in the substrate 5. In this way it is possible to make a radiation beam, which is directed at the record carrier in order to record digital information, accurately coincide with said servo track 4, in other words to control the position of the radiation beam in a radial direction *via* a servo system which employs light reflected by the record carrier. The radial position of the radiation spot on the record carrier can be measured in accordance with systems similar to those employed in optical record carriers provided with a video signal and as *inter alia* described in "I.E.E.E. Transactions on consumer electronics", Nov. 1976, page 307.

In order to enable digital information to be recorded, the record carrier body is provided with a layer of a material 6 which, if exposed to suitable radiation, is subject to an optically detectable change. In principle only the information portions 9 of the sectors need be provided with such a layer. However, for reasons of manufacturing technology it is simpler to provide the entire record carrier surface with such a layer. This layer 6 may for example comprise a thin layer of a metal such as tellurium. This metal layer can be melted locally by laser radiation of sufficiently high intensity, so that locally this information layer 6 is given a different reflection coefficient, as a result of which the reflected radiation beam is amplitude-modulated in accordance with the recorded information when an information track thus inscribed is scanned by a read beam.

Alternatively, the layer 6 may take the form of a double layer of materials, for example aluminium on iron, which react chemically to incident radiation. At the location where a high-power radiation beam is incident on the disc $FeAl_6$ is formed, which is a poor reflector. A similar effect is obtained in the case of a double layer of bismuth on tellurium, Bi_2Te_3 being formed. It is also possible to employ a single layer of tellurium.

As with the aid of the servo track in the form of a groove in the substrate 5 the write radiation spot is made to coincide accurately with said servo track, in particular when an information area is being scanned, the digital information modulating the write beam is exactly recorded in the information area coinciding with said servo track.

As is apparent from the foregoing, the record carrier intended for the user, in which the information areas do not yet contain information, have a groove structure in said information areas within the sectors. Moreover, within each sector such a record carrier has a synchronization area 8 in the form of an optically detectable relief structure. Figure 1*b* on an enlarged scale shows a part of a track 4, from which the sequence of a number of information areas 9 and synchronization areas 8 is apparent. In this case the synchronization areas 8 comprise a relief structure constituted by a sequence of recesses alternating with intermediate areas. The depth of the recesses in this structure of the synchronization area is greater than the depth of the servo track in the information area 9. This depth of the recesses is selected in accordance with general optical rules and depending on the shape of said recesses in the selected read system in such way that an optimum read-out of the information represented by the structure is obtained. In the case of a read system in which the radiation beam reflected by the record carrier is detected by a single photo-detector, 1/4 λ may be selected as the depth for the recesses, λ being the wavelength of the radiation used. If for the depth of the servo track in the information area 9 the value 1/8 λ or smaller is selected, this servo track will hardly affect the amount of light detected by the detector.

In order to illustrate further the structure of the synchronization area, Figure 1*c* again shows such a synchronization area on an enlarged scale, the information layer 6 being omitted for the sake of simplicity. Such a synchronization area 8

comprises two portions, namely an indication portion 10 and an address portion 11. The address portion 11 contains all the information required for controlling the recording process. When recording digital information, this information is converted into a so-called word-organized bit series. This address portion contains information about the word organization, so that during recording the location of the bit words is defined and during reading the bit words are suitably decoded. Furthermore, this address portion 11 contains information about the relevant track number. This information takes the form of a relief structure in accordance with a digital modulation technique suitable for the recording medium. In addition to the servo track in the form of a groove in the information portions 9, the record carrier therefore in the synchronization area already contains all the information required for positioning information in the form of a bit-word-organized bit series in said information areas, consequently the requirements imposed on the write and read apparatus employed by the user may be less stringent. Furthermore as this fully prerecorded information is formed in the record carrier as a relief structure, said record carrier is particularly suitable for mass-production, enabling customary pressing techniques to be used.

Figure 3, in Figures 3*a* to 3*d* schematically represents a part of such a servo track 4 in a cross-section in the longitudinal direction of said servo tracks 4 with a part of the synchronization area 8 and a part of the information area 9, Figure 3*a* showing such a cross-section of a blank prepared disc using the known technique, Figure 3*b* showing such a cross-section after digital information 14 has been recorded in the information area 9, Figure 3*c* showing such a cross-section of a blank prepared disc provided with clock information, and Figure 3*d* representing the cross-section of Figure 3*c* after information 14 has been recorded in the information area 9. Figure 3*e* schematically represents the signal obtained when reading the part of the track 4 shown in cross-section in Figure 3*d* and Figure 3*f* schematically shows a plan view of a part of the track 4 after information has been recorded in a manner other than represented in Figure 3*b* and 3*d*.

The prepared disc is provided with a servo track 4, formed in a substrate 5, for example by means of a laser beam. By modulating the intensity of the laser beam it is then possible to form a relief structure of "pits" 13 containing information in the synchronization area 8. Subsequently, the entire disc, including for the sake of simplicity the portion of the record carrier 1 outside the grooves 4, may then be coated with the reflecting information layer 6. In the record carrier thus prepared information can be recorded in the information area 9 by forming holes 14 in the reflecting information layer 6, for example by means of a laser beam. Such an inscribed record carrier is shown in Figure 3*b*. When information is written, i.e. the holes 14 are formed, and when the information is read, for example by means of a laser beam, it is of importance that this information writing or reading process is synchronized with the aid of a clock signal, about which the synchronization areas 8 may contain information. In order to ensure that during writing and reading a suitable synchronous clock signal is available continuously, *i.e.* also during writing or reading in the information areas 9, the servo groove 4 is provided with a structure which produces a modulation of the light reflected by the information carrier when the servo track 4 is followed during reading or writing.

However, this structure should be such that it does not disturb the read-out of information. How this is possible is explained with reference to Figures 4 and 5, Figure 4 representing the random power spectra of three possible binary information-signal modulations and Figure 5 being a diagrammatic representation of said modulations.

The reference *a* in Figure 5 designates a modulation known by the name of "biphase" modulation. The applied digital signal is then converted into a binary signal which for a logic "one" of the applied digital signal is positive during the time interval T/2 and negative during the next time interval T/2, T being the bit length of the applied digital signal. A logic "zero" yields exactly the opposite binary signal, *i.e.* negative for the time interval T/2 and positive for the next time interval T/2. This modulation technique yields a binary signal which has a power spectrum as represented by *a* in Figure 4. The frequency fo then corresponds to 1/T.

The reference *b* in Figure 5 represents the modulation known by the name of "Miller" modulation. The binary signal generated by means of this modulation has a transition halfway a logic "one" of the applied digital signal and at the transition of two consecutive logic "zeros". The frequency spectrum of the binary signal obtained by means of this modulation technique has the designation *b* in Figure 4.

Finally, the reference *c* in Figure 5 represents a modulation known by the name of "quadphase" modulation, the applied bit series of the digital signal first of all being divided into consecutive groups of two bits. From each two-bit group having a duration of 2T a binary signal is derived which in a first time interval T has the same variation as the original two bits and in the next time interval T an inverse variation. The bit combinations 11, 00, 01 and 10 which are possible are thus converted into the bit combinations 1100, 0011, 0110 and 1001 respectively. The binary signal obtained by means of this modulation technique has a frequency spectrum as is represented by *c* in Figure 4.

It is evident from Figure 4 that these modulation techniques have the common property that the resulting binary signal exhibits no strong frequency components at comparatively low frequencies, for example frequencies below 0.2fo. This is very useful when an optical record carrier is

used with the associated write and read systems. As stated previously such systems employ both a service control in order to keep the scanning spot accurately focused on the record carrier and a servo control which controls the radial position of the scanning spot and ensures that said scanning spot accurately coincides with the information track. As the control signals required for these servo controls are derived from the radiation beam which is reflected by the record carrier, which is also modulated by the relief structure of the synchronization area, it is essential that the frequency spectrum of the binary signal stored in the address portion does not contain any strong frequency components within the frequency band intended for the control signals. Figure 4 thus shows that the frequency band below approximately 0.2fo is suitable for such control signals. The control signals for the said servo systems may for example extend to a maximum frequency of 15 kHz. If for the frequency fo = 1/T for example the value 500 kHz is selected, it will be evident from Figure 5 that the binary signals *a*, *b* or *c* only exhibit very weak frequency components at frequencies of 15 kHz and lower. Furthermore it is apparent from Figure 4 that at the frequency 2fo and in the case of modulation method *c* the spectrum also has zero points at the frequency fo. Thus, it is possible to provide the record carrier with a clock structure of the frequency 2fo without interference with the information signal. Zero points at the frequency 2fo also occur in the case of other modulation methods. When quadphase modulation (modulation *c*) is used and also in the case of some other modulation methods, the frequency fo is highly suitable for this purpose, said frequency corresponding to the bit frequency 1/T, so that this quadphase modulation becomes very attractive. Also in the case of modulation method *b* a structure with the frequency fo may be used in some cases, because the components of the spectrum of modulation *b* are comparatively small at said frequency. Furthermore, it is theoretically possible to give the structure a modulation corresponding to a frequency higher than 2fo, but in practice this is generally not feasible. Indeed, in view of a maximum information density, the dimensions of the pits 13 and 14, which at a specific speed of rotation of the disc 1 at least correspond to a bit length of 1/2T, are selected nearest the resolution of the write/read system used, so that a surface structure corresponding to frequencies higher than 2fo will hardly be detectable. By means of special modulation techniques it is also possible to obtain zero points in the power spectra at frequencies other than fo or 2fo, for example at 1/2fo. Furthermore, reference is made to the Applicant's previous non-prepublished Netherland Patent Application No. 8006165, which describes an improved modulation technique.

Figure 3*c* show a cross-section of a record carrier corresponding to the cross-section of Figure 3*a*, whose surface at least at the location of the track 4 has been provided with a relief structure having a height *d*. A possibility of realizing this structure is to modulate the laser by means of which the synchronization area 8 and the groove 4 of the information area 9 is formed. In the present example this has only be done in the synchronization area 8 between the pits 13 by limiting the intensity of the laser beam. However, in principle it is also possible to provide the bottoms of the pits with a relief structure. As is shown in Figure 3*d* the record carrier can also be provided with information by forming holes 14 in the reflecting layer 6 covering the relief structure. Figure 3*e* shows an example of a signal obtained when reading a relief structure in accordance with Figure 3*d*. This signal exhibits minima at the location of the pits 13 or the holes 14 and an amplitude modulation (*d* in Figure 3*c*) corresponding to the modulation structure with the frequency fo at the maxima. The modulation structure of the bottoms of the holes 14 hardly contributes to the signal, because it hardly reflects any light owing to the removal of the reflecting layer 6. In this respect it is to be noted that it is for example also possible to provide a non-reflecting layer 6 on a reflecting substrate 5, which layer is locally removed. As a result of this the modulation of the frequency fo will be read satsifactorily at the very locations 14 where the non-reflecting layer has been removed.

In Figures 3*a*—3*d* the pits 13 or the holes 14 are shown as continuous holes or pits, i.e. in the case of more than one bit as an elongate slot having a length corresponding to the number of consecutive bits. However, it is alternatively possible to provide a separate pit or hole for each bit. Figure 3*f* illustrates this and shows a track 4 in which the clock modulation structure is represented by different types of hatching. In the synchronization area 8 the pits 13 may for example be formed in the centre of the maxima or minima of the structure and are also coated with a reflecting layer 6, which is symbolized by the hatching through said pits 13. In the information portion 9 the information holes 14 may be formed in the reflecting layer 6 at the maxima and minima of the clock information structure. Alternatively — as is represented by the information area 9′ in Figure 3*f* — holes 14′ may be formed at the zero points of the information structure. In this respect the location of the pits 13 or holes 14 is not essential, provided that the phase relationship with the clock information structure is fixed and known. Neither is the shape of the information structure of great significance. Instead of the rectangular shape shown in Figure 3 it may well have a sinusoidal shape, which is readily possible in the case of manufacture by means of a modulated laser beam. It is of importance only that said clock synchronization structure exhibits a frequency component which can readily be detected at the frequency fo or 2fo and which exhibits no strong components within the spectrum of the synchronization or digital-information signal recorded or to be recorded,

which is generally the case when the clock information structure *d* has a fundamental frequency fo or 2fo with higher order harmonics only; the next harmonic is then 2fo or 4fo, which as is shown in Figure 4 falls beyond the part of the information spectrum which is of interest.

Figure 6 illustrates schematically how structures in accordance with Figure 3 can be realized. Figure 6*a* shows an apparatus for manufacturing a record carrier in accordance with Figure 3*c*, Figure 6*b* shows an apparatus for recording information in the record carrier of Figure 3*c*, and Figure 6*c* shows an apparatus for reading such an inscribed record carrier.

In the apparatus of Figure 6*a* the beam 16 from a laser 15 is projected at a rotating disc 1 *via* for example an intensity modulator 57, a mirror 17 and a focusing optic 18, in order to form the spiral groove 4 (Figure 1). The laser 15 is controlled by a circuit 20 for pulsating the laser 15 so as to form the pits 13 (Figure 3) in the synchronization area 8. The modulator 57 is controlled by a source 19 having a frequency fo (or 2fo) in order to realize a clock modulation structure in the groove 4. Alternatively, it is possible to modulate the laser 15 itself. The disc 1 is driven by a motor 21 which for the purpose of speed control is provided with a servo control, which may for example comprise a tachogenerator 22, a speed-reference source 24 and a servo-amplifier 23. In order to ensure that the recording areas 8 are situated at the correct locations on the disc in the track 4 and, as the case may be, to obtain a correct tangential distribution of the modulation fo on the disc, the circuit 20 and, as the case may be, the source 19 of the frequency fo may be locked to the servo control. Furthermore the circuit 20 is controlled by the source 19 in order to guarantee a correct phase relationship of the synchronization pits 30 with the clock modulation structure. After this process the disc 1 may be provided with the said layer 6.

Figure 6*b* schematically represents an apparatus for providing the prepared disc 6 with information and simultaneously reading the clock modulation structure. This apparatus comprises the rotating disc 1, and a laser 15 whose beam 16, *via* a semitransparent mirror 17 and a focusing optic 18, is projected onto the disc 1. A reflected beam 60 is detected by means of a cell 27, for example a photodiode, and converted into an electric signal from which by means of the band-pass filter 28 the component of the frequency fo (or 2fo) is extracted, which component is mainly produced by the clock modulation structure formed in the track 4. As the case may be, this signal may also be applied to a phase-locked loop 29, which improves the filtration, which increases the constancy of the clock signal and, as the case may be, compensates for brief signal dropouts. The clock signal is then available on output 31. Data can be recorded by pulse modulation of the laser beam 16, directly by including a modulator in the beam or, as is shown in Figure 6*b*, by modulating the laser itself with a write modulator circuit 25, to which the information is applied *via* an input 26 and which is synchronized with the clock signal on output 31.

Via the light-sensitive cell 27 and a read circuit 30 the information contained in the synchronization portions is recovered from the reflected beam 60, which information appears on an output 32. This read circuit 30 may also be synchronized with the clock signal on output 31. Said information may be used to synchronize the circuit 25 and to locate the correct position on the disc. This information is also used in a servo control, not shown in Figure 6*b*, for radially positioning the optic 18 and the mirror 17, for inscribing the desired portion of the track 4 and for controlling the drive of the disc 1, which is symbolically represented by the dashed line 62 in Figure 6*b*.

Furthermore, the apparatus may be provided with a tracking circuit 33 which derives a tracking signal from the signal supplied by the cell 27 in order to keep the beam 16 on the track 4 by controlling the angle relative to the beam 16 of the mirror 17, which is symbolized by the dashed line 61 in Figure 6*b*. Such a tracking circuit is for example described in USP 4,223,182.

Figure 6*c* shows an apparatus for reading an inscribed disc 1, which apparatus is generally combined with that of Figure 6*b*. The apparatus again comprises a laser 15, whose beam 16 is projected onto the disc 1 *via* a mirror 17 and the optic 18. The reflected beam 60 is detected with a detector 27 in the form of a photodiode and the resulting electric signal is passed through a band-pass filter 28 having a pass frequency fo and a phase-locked loop 29 tuned to the frequency fo, so that the clock signal of the frequency fo (or 2fo) is available on output 31. The information recorded on the disc is decoded from the electric signal supplied by the photodiode 27 by means of the read circuit 30, so that on an output 32 thereof the digital information and the information contained in the synchronization areas 8 is available. This read circuit is synchronized by means of the clock signal on output 31. In addition a tracking signal may be derived from the beam detected by a photodiode 27 by means of a tracking circuit 33, in order to control the mirror 17 in such a way that the beam 16 exactly follows the track 4. The disc drive motor 21 may be included in a servo control, for example comprising a tachogenerator 22, a reference source 24, and a servo-amplifier 23, in order to control the speed, which control may be locked to the read circuit 30. Furthermore, the apparatus also comprises a control mechanism 35 for moving the optic 18 together with the mirror 17 and the detector 27 — the complete mechanism being designated 36 in Figure 6*c* — in a radial direction, so that at option a specific part of the disc can be read controlled by information applied to an input 37 of the control mechanism 35 and by the information produced by the synchronization areas and available on output 32 of the read circuit 30.

The clock information structure which is or has been recorded in track 4 may take various forms. Figure 7 shows a number of examples thereof. Figure 7*a* schematically represents a track 4 in which the clock information is formed by a height variation — symbolically represented by the interrupted hatching — for example by modulating the intensity of the laser beam that writes the track 4, Figure 7*b* shows the track 4 in which the clock information is formed as a width variation of the track 4, for example by modulation of the laser-beam focusing, for which for example the objective 18 (Figure 6*a*) may be controlled by means of the device 59 (Figure 6*a*) — whilst a combination of width and depth variations is also possible, which in practice will frequently be the case when the intensity or focusing of the laser beam is modulated — and Figure 7*c* shows the track 4 in which the clock information takes the form of a radial variation of the position of the track 4, for which purpose for example the angle of the mirror 17 (Figure 6*c*) relative to the beam 16 can be modulated by means of the device 58. All the variations shown then have a period length Lo which is equal to Lo = V/f, where V is the tangential speed of the disc 1 at said location and *f* the frequency of the desired clock signal, which frequency *f* corresponds to a zero point in the random frequency spectrum of the data to be recorded, for example the frequency fo (Figures 4*c* and 5*c*) in the case of "quadphase" modulation.

One of the possibilities of obtaining a tracking signal is by providing a radial "wobble" in the groove-shaped track, for example by controlling the mirror 17 (Figure 6*a*, with for example a sinusoidally varying radial excursion with a wavelength on the disc which during playback at the normal speed produces a light intensity variation detected by the detector 27 (Figure 6), whose frequency is situated beyond the spectrum of the data, *i.e.* for example below the frequency 0.2fo (Figure 4), as is for example described in said USP 4,223,187. For example by synchronous detection, a measure of the deviation of the centre of the detector relative to the centre of the track 4 may be derived from said signal component. Such a radial wobble may be combined with a clock modulation structure, for example the clock modulation structure shown in Figure 7*a*, which combination is shown in Figure 7*d*. A special combination is obtained when the wobble on the disc has a wavelength equal to that of the clock modulation structure with a fixed phase relationship, which makes synchronous detection superfluous. Figure 7*e* shows such a structure, a depth modulation structure (represented by alternately hatched and non-hatched areas) in track 4 being combined with a radial positional variation which is 90° shifted relative thereto (*i.e.* a quarter of the period of said structure), which structure can be produced with the apparatus of Figure 6*a* by modulating the angle of the mirror 17 relative to the beam 16 with the aid of the device 58. If the depth modulation structure is then selected so that the "shallow" parts of these modulations coincide with the surface of the disc-shaped record carrier 1, the servo track 4 will take the form of a sequence of radially asymmetrical pits which are tangentially spaced from each other by distances equal to the said distance Lo. Figure 7*f* shows an example of such a track 4.

Figure 8a illustrates the principle of the read section of an apparatus for writing data in or reading data from a record carrier. The apparatus comprises a photodetector 27, past which the track 4 is moved. The signal which is supplied by the detector 27 has a spectrum as shown in Figure 8*b*, in the present example with the spectrum of a quadphase modulated signal Sd and a clock signal Sc. The clock signal Sc is extracted with the aid of a band-pass filter 28, preferably followed by a phase-locked loop 29. The clock signal Sc is available on output 31. The digital signal Sd, *i.e.* the signal recorded in the synchronization area 8 and during reading the signal recorded in the synchronization area 8 and in the information area 9, is detected with a read circuit 30, which read circuit 30 is synchronized with the clock signal Sc. The data signal read is available on output 32. Furthermore, a radial tracking signal can be derived from the signal from the detector 27. When information is recorded in information areas 9 the read circuit 30 only detects the information contained in the synchronization areas 8, which together with the clock signal Sc is then applied to the write circuit 25 in order to modulate the beam of a write laser 15.

When a low-frequency radial wobble is used in order to obtain a radial tracking signal, the apparatus of Figure 9*a* may be used, Figure 9*b* showing the frequency spectrum of the signal detected by the detector 27. When a track 4 with a radial wobble is read it is effective to employ a photodetector 27 which is divided in two sections *a* and *b* along an axial line. A differential amplifier 40 or equivalent means forms the difference of the signals detected by sections *a* and *b* and a summing amplifier 41 or equivalent means provides the sum of said signals. The frequency spectrum (Figure 9*b*) again contains the spectrum of the quadphase modulated signal Sd, the clock signal Sc and the low-frequency signal Sw produced by the wobble. In the sum signal the wobble manifests itself as an amplitude modulation with the clock signal Sc as carrier wave, which in Figure 9*b* is represented as side bands Sc − w and Sc + w, which side bands have an amplitude equal to zero when the detector 27 exactly follows the centre 45 of the track 4. Filtering the sum signal with the band-pass filter 28 yields the clock signal Sc and, if the filter is not too narrow-banded, also said side bands. The output signal of said band-pass filter 28 is applied to the phase-locked loop 29 and on an output 31 thereof the clock signal Sc is available. The output signal of this band-pass filter 28 is also applied to a synchronous demodulator 42 together with the clock signal Sc. This demodulator then produces the modulation Sw.

The frequency of the radial wobble is recovered

from the difference signal from amplifier 40 with the air of band-pass filter 38 and phase-locked loop 39, which frequency together with the output signal of the synchronous detector 42 is applied to a synchronous detector 43. On the output 44 thereof the modulation of the wobble signal Sw is then available, which may be used as a radial tracking signal and is representative of the deviation of the detector 27 relative to the centre of the track 4, which in Figure 9*a* is represented by the dashed line 45. Said radial tracking signal can then control the mirror 17 as is symbolically represented in Figures 6*b* and 6*c*.

The data contained in the track 4 is then recovered from the sum signal on the output of amplifier 41 in a similar way as in the apparatus of Figure 8a. In respect of information recording similar steps may be applied as in the apparatus of Figure 8*a*, which also is valid for the apparatus of Figure 10, Figure 11a and Figure 12.

Figure 10 shows a variant of the apparatus in accordance with Figure 9, which yields a better signal separation. The detector 27 has also been divided in accordance with a tangential line, so that four quadrants *a, b, c* and *d* are obtained, the sections *a, b* and *c, d* respectively being situated on either side of the tangential line, and the sections *a, c* and *b, d* respectively being situated on either side of the radial line. An amplifier 41 or equivalent means determines the sum of the signals generated by the sections *a, b, c* and *d*, so that this amplifier is specifically sensitive to intensity variations of the beam reflected by the track 4, *i.e.* to the data signal Sd, an amplifier 421 determines the difference between the sections *a* + *b* and *c* + *d* situated on either side of the tangential line, so that said amplifier 421 is particularly sensitive to variations of the track 4 in a tangential direction, *i.e.* to the signal Sw, and an amplifier 46 determines the difference between the sections *a* + *c* and *b* + *d* situated on either side of the radial line, so that this amplifier is particularly sensitive to variations of the track 4 in a radial direction, *i.e.* to the clock signal Sc.

In a similar way as in the apparatus of Figure 9*a* the clock signal Sc is recovered from the output signal of amplifier 46 by means of band-pass filter 28 and phase-locked loop 29 and the frequency of the wobble signal Sw by means of band-pass filter 38 and phase-locked loop 39. The output signal of the band-pass filter 28, which contains the wobble signal Sw as an amplitude modulation of the clock signal Sc, is detected synchronously with the clock signal by means of synchronous detector 42 and yields the wobble signal Sw whose amplitude variation represents the deviation of the detector 27 relative to the centre 45 of track 4. Said signal Sw is detected synchronously with the output signal of phase-locked loop 39, *i.e.* the wobble frequencies, by means of synchronous detector 43, so that the radial tracking signal appears on output 44. The data signal is recovered from the output signal of amplifier 41, synchronised by the clock signal Sc, by means of the read circuit 30.

Mathematically, the operation of the apparatus of Figures 9*a* and 10 in respect of the recovery of the radial tracking signal may be explained as follows. The signal I detected by the detector 27 is a product of the clock modulation, the wobble modulation and the radial tracking error, which (when ignoring the data signal) may be expressed as:

$$I = Ar \sin(w_w t) \sin(w_c t)$$

where Ar is a function of the tracking error, w_w the angular frequency of the wobble signal Sw, w_c is the angular frequency of the pilot signal Sc, and t the time. Synchronous detection with the pilot signal Sc yields the terms $Ar \sin(w_w t)$ and subsequent synchronous detection with the wobble frequency w_w yields the signal Ar. Similarly, the division of the detector 27 along a radial line only may be employed in order to increase the sensitivity to the clock signal Sc in the apparatus of Figure 8*a*.

Figure 11*a* shows a read section of an apparatus for reading data from a track 4 with a clock modulation structure and a wobble for deriving a radial tracking signal, the frequency of the wobble signal Sw being substantially equal to the frequency of the clock signal Sc, and Figure 11*b* shows the frequency spectrum in which Sd represents the data signal and Sc — w the term having a frequency equal to the difference between the frequencies of the clock signal Sc and the wobble signal Sw which difference is for example 30 kHz, said term being obtained in that the photodetector 27 receives the product of the wobble modulation and the clock modulation. As a result of this, said term is situated in the low-frequency part of the spectrum and is hardly disturbed by the digital information. The amplitude of this term constitutes the radial tracking signal. The amplitude is zero if the centre line 45 of the track is followed exactly. The wobble then yields a term of double the difference frequencies, which term is not used, and a term with the wobble frequency itself.

The apparatus, in a similar way as in the apparatus of Figure 10, comprises an amplifier 41 for supplying the sum of the signals supplied by sections *a, b, c* and *d* of photodiode 27, from which sum the term of said difference frequency is extracted by means of the band-pass filter 48. With the aid of a synchronous detector 43, to which said difference frequency is applied, this term is demodulated and, as the case may be *via* a low-pass filter 49, the radial tracking signal appears on output 44.

The clock signal Sc is obtained in a similar way as in the apparatus of Figure 10 by determining the difference between the signals supplied by the two radial halves a + c and b + d of photodiode 27 with amplifier 46 and applying said difference to a phase-locked loop 29 after filtration with band-pass filter 28. In a similar way as in the apparatus of Figure 10 the wobble signal

Sw is derived by determining the difference between the signals supplied by the two axial halves $a + b$ and $c + d$ of photodiode 27 with amplifier 421 and applying this to a phase-locked loop 39 *via* a band-pass filter 38. The difference frequency applied to the read circuit detector 43 is obtained by applying the clock signal Sc thus obtained and the wobble signal Sw to a synchronous detector 42, after which the resulting signal of said difference frequency is applied to synchronous detector 43 *via* band-pass filter 47.

With the read circuit 30, synchronized with the clock signal Sc, the data signal can be recovered from the output signal of amplifier 41.

If the frequency of the wobble signal Sw is selected to equal the frequency of the clock signal Sc, it will be evident from Figure 11*b* that the term with the difference frequency directly constitutes the DC tracking signal. This tracking signal can then be obtained without synchronous detection.

The phase difference between the two track modulations should be unequal to zero, because only one modulation can be distinguished when the two modulations are in phase. It is found that 90° is an optimum phase difference.

Figures 7*d* and 7*e* show such a structure, which can be read with the simple read circuit of Figure 12.

In the apparatus of Figure 12 the photodetector 27 is divided into two radial halves *a* and *b* for an optimum detection of the clock signal Sc, which is obtained on output 31 by determining the difference between the signals supplied by the two halves *a* and *b* with amplifier 46, by filtering said signal with band-pass filter 28 and applying it to the phase-locked loop 29. By filtering the output signal of amplifier 46 with a low-pass filter 49 the radial tracking signal is directly available on output 44. The digital signal is recovered from the difference signal with read circuit 30, which is synchronized with the clock signal Sc. Alternatively, it is possible to recover the data signal and the low-frequency tracking signal from the sum of the two halves.

In respect of the tracking during the recording of data signals the apparatus in accordance with Figures 8*a* to 12 may be extended with a device modulating a laser beam 16, which device is synchronized with the clock signal Sc and the signal read from the synchronization areas, as has been explained with reference to Figure 6*b*.

In the foregoing it has each time been assumed that one detector 27 is used which detects the reflected beam 16 (Figure 6). Especially at high bit frequencies it may be problematic, when recording data in the information areas 9 with a laser beam which is comparatively powerful relative to that used for reading, to recover the clock information from the beam which is reflected between every two write pulses. As in many cases a follower laser-beam is employed in order to enable the recorded data signal to be detected, the apparatus of Figure 13 may be used in such cases, in which the track 4, which relative to the detector 27 travels in the direction of the arrow 63, is scanned by an information-writing beam 16*a* and a follower beam 16*b*, which beams can for example be obtained by means of a beam splitter 68, mirrors 70*a* and 70*b* and optical systems 18a and 18b. In order to modulate the beam 16a a modulator may be arranged in the beam 16a. Said apparatus comprises a photodetector 27 in the form of a photodiode, which in respect of the reading of data signals and tracking signals fully corresponds to the apparatus in accordance with any of the Figures 8a, 9a, 10, 11a or 12a. Furthermore, the apparatus comprises a photodetector 50 in the form of a photodiode for detecting the reflection of the follower beam 16b which is projected at the track at some distance behind the beam 16a. During the read process and also when the synchronization areas 8 are being read the clock signal Sc is obtained by applying the signal detected by photodetector 27 to the phase-locked loop 29 *via* an amplifier which for simplicity is not shown in this Figure (for example 46 in Figure 11a) and a band-pass filter (for example 28 in Figure 11a). In addition, in particular during the writing process, said clock signal is also recovered in a similar way from the signal detected by photodetector 50, as the case may be *via* a band-pass filter not shown and *via* a phase-locked loop 501, but this signal is delayed relative to the clock signal obtained *via* photodetector 27. *Via* a delay device 51 the output signal is applied to output 31. The phase of the delayed clock signal is then compared with the phase of the clock signal obtained by means of the photodetector 27 in phase comparator 52 and *via* switch 53 the delay device 51 is adjusted so that the clock signal from photodetector 50, which has been delayed *via* delay device 51, is in phase with the signal obtained *via* photodetector 27. During the read-out of the synchronization areas 8 switch 53 is closed and the delay device 51 is adjusted so that the clock signal from photodetector 50, which has been delayed by said delay device 51, is in phase with the clock signal obtained *via* photodiode 27. During the recording of data in the information areas 9 switch 53 is open and the clock signal is recovered from the reflected auxiliary beam 16*a* *via* photodetector 50 and is delayed with the delay device 51 by the time adjusted during the read-out of the synchronization areas 8. The switch 53 is operated on command of the synchronization signals read from the synchronization areas by the read circuit 30.

In this respect it is to be noted that writing information with unit pits, *i.e.* the information is recorded with separately detectable changes in the surface structure of the record carrier, as is shown in Figure 3*f*, yields a frequency component at the frequency 2fo in the spectrum (Figure 4) of the signal being read. This need not be a problem for the use of a clock modulation structure, because this clock modulation, if it has a frequency equal to 2fo, may be used when recording information, and if during recording a correct phase relationship with the clock signal is maintained during read-out it will coincide with

the component 2fo as a result of the use of unit pits. When quadphase modulation is used (Figures 4*c* and 5*c*) the clock signal will have a frequency equal to fo and in that case said component of the frequency 2fo is not disturbing.

As a result of all kinds of disturbances, such as local flaws in the disc 1 or shocks, it may occur that during writing the laser beam — when this beam is writing in a specific sector 9 (Figure 16) of a track — comes off the track and passes over an adjacent track, thereby writing over the relevant sector, which sector has already been inscribed or is to be inscribed. Although the radiation tracking mechanism will be capable of returning the beam to the track, this situation is undesirable because, apart from the fact that the original section to be inscribed is inscribed incompletely, the adjacent sector or sectors should be regarded as lost. This situation is to be avoided. The recording process should be stopped when the beam leaves a track, so that no adjacent tracks are damaged. The sector 9 which is inscribed at the instant is then lost and the information is to be re-recorded in a new sector 9. A reliable method of duly detecting an excessive tracking error can be applied by means of the disc 1 described with reference to Figures 14 and 15. Said disc contains preformed tracks 4 with clock information, as described with reference to Figures 1—13. However, the clock modulation is arranged so that points of equal phase depart from the radial direction B along line A. As a result of this, the phase of the clock structure in track 44 exhibits a positive phase difference with the clock structure in track 4′ and a negative phase difference with the clock structure in track 4″.

When the beam 16 leaves the track 4, depending on the direction, a positive or a negative phase shift relative to the monotonous phase variation will occur in the clock signal being read when following the track 4. This phase shift can be detected and from its amplitude a signal, indicating an impermissible departure from the track can be derived in order to stop the write process. From the polarity of the phase shift information about the direction of the tracking error can be derived, which information may be utilized for returning the beam 16 to the track 4, so that the write process can be continued in the next sector 9.

In Figure 4 the phase difference between the clock modulations of consecutive tracks is always 90°. This is the optimum phase relationship; indeed a phase difference of 0° or 360° yields no error signal, whilst a phase difference of 180° does not provide any directional information. An additional advantage of the disc in accordance with Figures 14 and 15 is that the influence of cross-talk during reading is reduced owing to the phase shift.

Figure 16 shows an embodiment of an apparatus for inscribing a disc in accordance with Figures 14 and 15. For the principle of operation reference is made to the description of Figures 1—13, especially Figures 6*b* and 12, in which corresponding reference numerals are used. In contradistinction to the apparatus shown in Figure 12 it is assumed that the tracks 4, 4′, 4″ ... exhibit a low-frequency wobble, as is for example described with reference to Figures 9 and 10. The device 33 for deriving the radial tracking signal should then also be adapted accordingly. Furthermore, in comparison with Figure 6*b*, the write modulator 25 is provided with an input 70. A signal on said input causes the write process to stop.

The phase-locked loop 29 in the apparatus shown in Figure 16 is provided with a synchronous demodulator 71, which compares the phase of the clock signal recovered *via* filter 28 with the signal obtained from a voltage-controlled oscillator 72, which oscillator 72 is controlled by the output signal of the demodulator 71 obtained *via* the low-pass filter 73. The output signal of the oscillator 72, which constitutes the clock signal Sc, is available on output 31. The output signal of the demodulator 71 is a measure of the instantaneous phase difference between the output signal of the oscillator 72 and the clock signal from the disc 1 *via* the filter 28.

If, as is shown in Figure 17*a*, a data track T is written in track 4, a specific sector 9 between synchronization areas 8 (see Figure 1), a monotonous clock signal Sc is obtained. The output signal of the demodulator 71 (shown in Figure 17*b*) is then substantially equal to zero. If, owing to any cause whatsoever, the recording track T moves from track 4 to track 4′, the output signal of the demodulator 71 will increase in order to correct the oscillator 72. The write process should be interrupted before the track T reaches the adjacent track 4′. This can be detected by means of the amplitude of the output signal of the demodulator 71. Similarly, the data track T may deviate in the other direction, which as is shown in Figure 17b gives rise to a negative output signal of the demodulator 71. A window detector 75 is connected to the demodulator *via* a low-pass filter 74, which detector detects whether the output signal of the demodulator 71 exceeds predetermined limits +Sd or —Sd (Figure 17*b*) and subsequently generates a signal on output 76 (Figure 17*c*), which causes the write process to stop *via* input 70 of the write modulator 25.

The low-pass filter 74 serves to render the system immune to spurious pulses and the like and may be combined with the low-pass filter 73, which is indicated by the dashed line 77 in Figure 16. If the data track T departs from the track 4, the tracking signal will also exhibit a greater positive or negative value than during tracking. *Via* a window detector 78 it is possible to detect this and to combine the output signal thereof with the output signal of the window detector 75 in a combining circuit 78, which possibility is represented by dashed lines in Figure 16. This double protection may be desirable in order to increase the reliability of the system. In fact the protection *via* the tracking signal is less suitable than the protection *via* the phase difference signal

on the output of the demodulator 71 because, as is shown in Figure 18, the tracking signal information is derived from a low-frequency part C of the spectrum and said phase difference signal information is derived from a high-frequency part E of this spectrum, whilst faults such as variations in the reflection of the disc and minor flaws in the disc surface, which would not give rise to a track change as shown in Figure 17*a*, mainly occur in a low-frequency part D of the spectrum.

CLAIMS

1. An apparatus for recording information on a record carrier comprising a disc-shaped substrate with a radiation-sensitive information layer and provided with information areas arranged in accordance with a spiral or concentric track pattern, the apparatus comprising a light source, an optical system for directing a light beam to the information areas of said record carrier, a recording circuit for modulating the light beam depending on the digital signal to be recorded, and an optical system with a detector for detecting the radiation which is reflected or transmitted by the record carrier, wherein for reading a record carrier in which the information areas exhibit a periodic track modulation, whose period corresponds to a frequency for which the power spectrum of the digitally coded information to be recorded or recorded at least substantially exhibits a zero point, for generating a clock signal of bit frequency for synchronizing the digitally coded information during recording and/or reproduction, said periodic track modulation being formed in the track in such a way that from track to track points of said track modulation of equal phase extend along a line which departs from the radial direction, so that the track modulation of each track as a function of the circumferential angle of the disc-shaped record carrier in the one radial direction always has a phase lead relative to track modulation of the adjacent track in said radial direction and in the other radial direction has a phase lag relative to the track modulation of the adjacent track in said other radial direction, the apparatus further comprises a band-pass filter for filtering a signal of a frequency determined by the period of the periodic track modulation out of said detected radiation, which signal is applied to a write circuit as a clock signal for synchronizing the information signal to be recorded with the periodic track modulation in such a way that the information to be recorded is recorded in a fixed phase relationship with said periodic track modulation and a phase comparison circuit for monitoring the instantaneous phase of said filtered signal in order to generate a signal for interrupting the recording process when the phase deviates to a predetermined extent from that of a signal of monotonously varying phase.

2. An apparatus as claimed in Claim 1, wherein the phase comparison circuit is included in a phase-locked loop, said phase comparison circuit receiving said filtered signal and the signal from an oscillator which is controlled by the output signal of said phase comparison circuit *via* a low-pass filter, the output signal of said phase comparison circuit being applied to a window detector.

3. An apparatus as claimed in Claim 1 or 2, provided with optical means for directing a light beam modulated with information to be recorded to the information areas and for directing an auxiliary beam to the information areas behind the modulated beam in order to read the information recorded by the modulated light beam, wherein the auxiliary beam for reading the periodic track modulation is used for generating the clock signal in order to synchronize the information recording process with the other beam and for supplying a signal to the phase comparison circuit.

4. An apparatus for recording information on a record carrier, substantially as hereinbefore described with reference to Figure 16 of the accompanying drawings.

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